Toward an improved representation of air-sea interactions in high-resolution global oceanic forecasting systems

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General context : air-sea interactions in eddying models

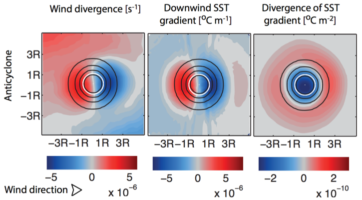
Thermal coupling

1. Downward mixing (e.g. Chelton, 2013; Frenger et al., 2013)

$$\left\{ \begin{array}{lll} \boldsymbol{\nabla} \times \boldsymbol{\tau} & = & c_1 \boldsymbol{\nabla}\mathrm{SST} \times \widehat{\boldsymbol{\tau}} \\ \boldsymbol{\nabla} \cdot \boldsymbol{\tau} & = & c_2 \boldsymbol{\nabla}\mathrm{SST} \cdot \widehat{\boldsymbol{\tau}} \end{array} \right.$$

2. Back pressure effect (e.g. Minobe, 2008; Lambaerts et al., 2013)

$$\boldsymbol{\nabla} \cdot \boldsymbol{\tau} \propto -\|\boldsymbol{\nabla}^2 \mathrm{SST}\|$$



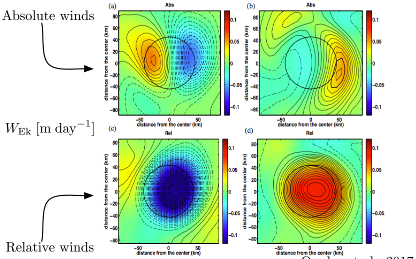
Frenger et al., 2013

Dynamical coupling

$$\boldsymbol{\tau} = \rho_a C_D \|\mathbf{u}_a - \mathbf{u}_o\| (\mathbf{u}_a - \mathbf{u}_o)$$

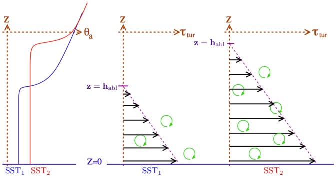
Acts as a "top drag" (e.g. Dewar & Flierl, 1987)

- Strongly reduced mesoscale activity (intensified eddy damping)
  (e.g. Renault et al., 2016)
- Strongly increases vertical velocity anomalies associated to eddies
  (e.g. Oerder et al., 2017)

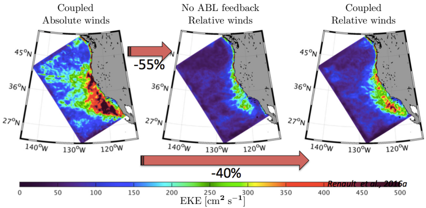


Oerder et al., 2017

Important processes



Downward mixing
(Source: Oerder, 2016)



Dynamical coupling
(Source: Renault et al., 2016)

Strong interactions at the characteristic scales of the ocean meso-scale

- ▷ Proper representation of those interactions requires an interactive ABL
- ▷ Atmospheric resolution must be ”eddy-resolving” (i.e. $\Delta x_{\rm oce} = \Delta x_{\rm atm}$)

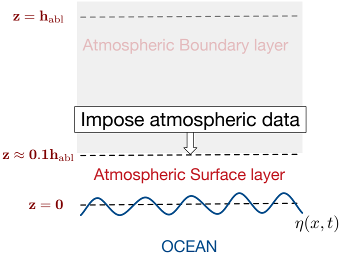
Limitations of current practices in global models

→ **Bulk forcing** (i.e. via an atmospheric surface-layer parameterization)

- effect of thermal coupling is under-estimated (no downward mixing)
- effect of dynamical coupling is over-estimated (wrong energy transfers)

→ **CheapAML** (Deremble et al., 2013)

- Designed for large scales (no thermal or dynamical coupling)



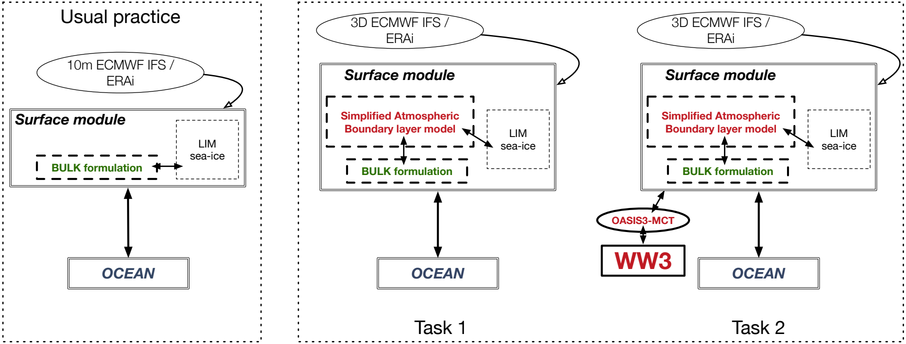
→ **Full-coupling**

- computationally unaffordable when $\Delta x_{\rm oce} = \Delta x_{\rm atm}$
- hard to find a good ”set” of parameterizations
- Initialization issues

Objective: find an alternative to force an eddying global operational model

The ALBATROSS Project

▷ High-resolution ocean, waves, atmosphere interaction



General approach : dynamical downscaling of atmospheric data to the oceanic resolution via a simplified MABL model (called SIMBAD) guided by operational weather forecasts or reanalysis (e.g. ERAi, operational IFS)

Current status of the project (1/2)

1. Define a single-column model (SIMBAD1d)

Integrate winds $\mathbf{u}$, potential temperature θ and specific humidity q

$$\begin{cases} \partial_t \mathbf{u} &= f\mathbf{k} \times (\mathbf{u} - \mathbf{u}_G) + \partial_z \left(\mathbf{K_m} \partial_z \mathbf{u} \right) \\ \partial_t \theta &= \partial_z \left(\mathbf{K_s} \partial_z \theta \right) + \lambda_s (\theta - \theta_{\mathrm{LS}}) \\ \partial_t q &= \partial_z \left(\mathbf{K_s} \partial_z q \right) + \lambda_s (q - q_{\mathrm{LS}}) \end{cases}$$

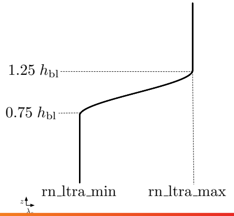
Blue terms are specified via large-scale data
Red terms are given by turbulent closure

- ▷ **Radiative forcing** is kept as it is
- ▷ **Surface boundary conditions** for $K_m \partial_z \mathbf{u}|_{z=0}$, $K_s \partial_z \theta|_{z=0}$, $K_s \partial_z q|_{z=0}$

$\rightarrow$ **IFS bulk formulation**

- ▷ used operationally at ECMWF
- ▷ consistent with large-scale data
- ▷ include sea-state and convective limit

▷ **Relaxation term** scales with PBL height

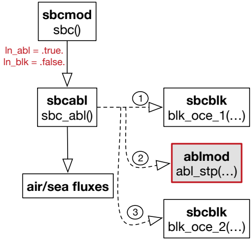


Current status of the project (2/2)

2. **Turbulent closure scheme** : TKE-based scheme of Cuxart et al. (2000)
   - ▷ used operationally at Meteo-France (e.g. in Arome and Meso-NH models)
   - ▷ recoded from scratch to allow more flexibility and better performances

3. **Development of preprocessing tools** to handle 3D IFS data and extract geostrophic winds

4. **Implementation in NEMO surface (SAS) module** in a generic way
   - Online interpolation of external 3D data
   - Option to split NEMO and SAS on separate nodes
   - Standalone mode
   - MPI capability



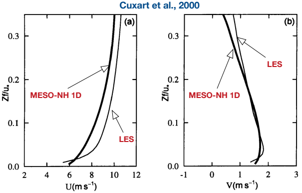
→ Computational cost considering the default Mercator settings & 50 vertical levels in the ABL :

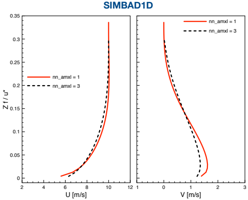
- + 12% in memory size
- + 7 - 12 % in elapsed time depending on namelist options

Current status of the validation strategy (1/2)

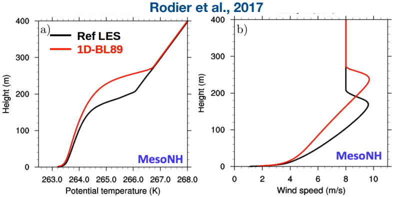
1. Validation of Simbad1d using standardized test-cases from the ABL community (see GABLS initiative)

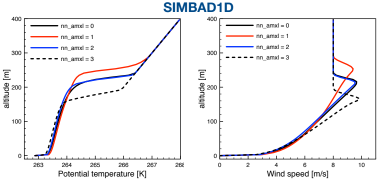
   → Neutral turbulent Ekman layer at 45^0N (Cuxart et al., 2000)





   → Stably stratified boundary layer (typical situation over sea-ice)

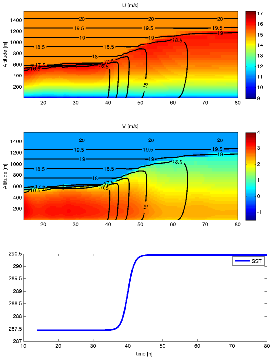




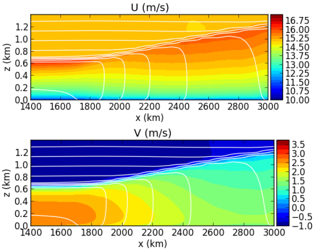
Current status of the validation strategy (2/2)

2. Winds across a Midlatitude SST Front (Kilpatrick et al., 2014)

SIMBAD1D



MESO-NH LES



2D x-z (solution at equilibrium)

3. NEMO1D / SIMBAD1D coupling at the PAPA station (50.1^oN, 144.9^oW)

$\rightarrow$ MSc of Théo Brivoal

- Extension of the work of Reffray et al. (2015) with NEMO to the coupled case

Expected benefits for CMEMS services

Expected benefits of added feedback loops :

- Consistent integration of each media (proper energy transfers)
- Impact on mixed layer extent and surface currents in ocean forecasting
- Better forcing of the dynamics in the tropics (improved seasonal forecasts?)
- Account for the effect of tropical cyclones in oceanic reanalysis
- Wind-SST and Wind-current interactions have strong impact on biogeochemistry

Perspectives & ongoing work

- **R. & D.**
  - Increased level of complexity in the MABL reduced model (add horizontal/vertical advection and fine-scale pressure gradient)
    $\rightarrow$ Simbad2d, Simbad3d
  - SIMBAD over sea-ice (multi-surface option) + waves
  - Initialization of the NEMO/SIMBAD coupled system (in collaboration with Arthur Vidard, Inria)
- **Validation strategy**
  - Global standalone simulation of SIMBAD relaxed toward ERAi & comparison with ERAi fluxes + sensitivity to oceanic data resolution
  - North-East Atlantic realistic simulation $(1/12^0)$ & comparison with fully coupled MESONH/NEMO simulations (PhD T. Brivoal)

Ongoing work & perspectives

- Initialization of the NEMO/SIMBAD coupled system
  (in collaboration with Arthur Vidard, Inria)

Objectives :

- Avoid initialization shocks (e.g. Mulholland et al. 2015) and more generally inconsistencies at the interface
  $\rightarrow$ consistency of air-sea fluxes in the analyzed state
- Account for cross-correlations in the error covariance matrices
  $\rightarrow$ ensemble method
- Enforce good regularity in time
  $\rightarrow$ iterative ensemble Kalman smoother (IEnKS)